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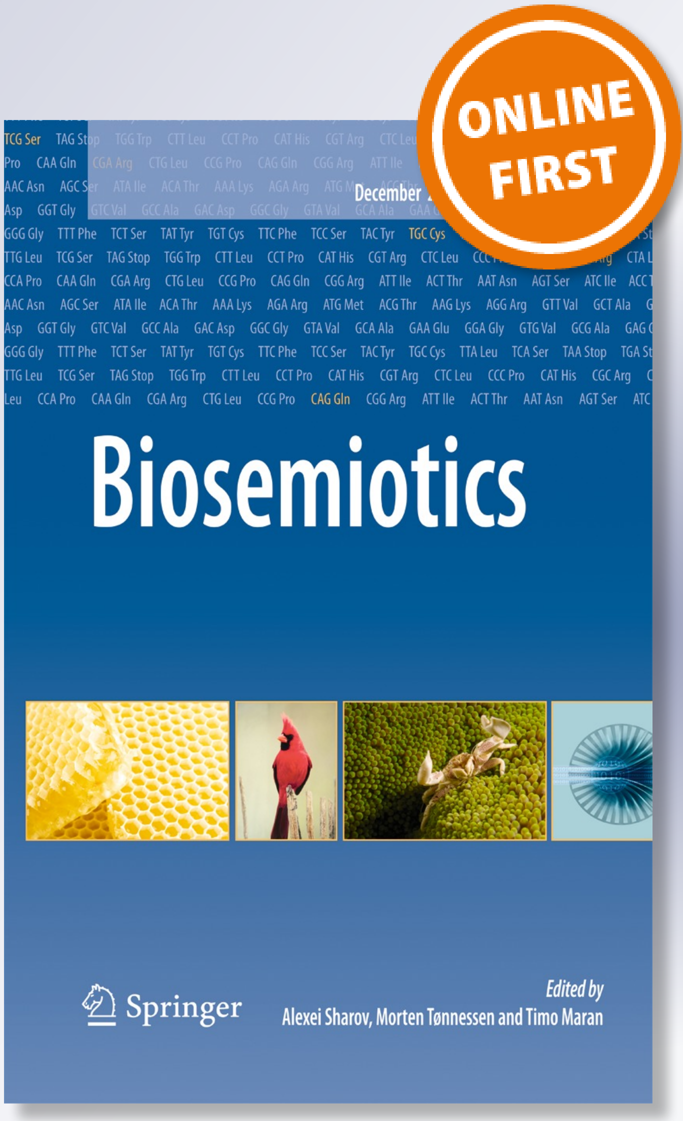

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Abstract Space is a product of semiosis. It is a condition pertinent to an organism's semiotic freedom, which is articulated by the organism as a consequence of its capacity to manipulate the world in the course of its unfolding interaction with its environment. Spatial configuration is thus the result of agency inherent in the organism-in-its-environment. Space, a consequence of social cohesion, is effected through constraints and processes of enaction which are semiotic. These processes are productive and offer architects a novel means by which to configure space, which they should embrace to articulate the nature of inhabitation. The model presented identifies activity as the essential building block to the generation of form. Modelled as a form of artificial life, swarm-like components, referred to as 'actants', represent discrete activities and self-configure according to differences in the environment they detect, to form a body-of-swarms. Thus, depicting the spatiality of being.

Keywords Space · Spatial organisation · Semiosis · Agency · Boundaries · Niches · Self-organisation · Emergence

Introduction

The basic unit of biotic being is the organism-in-its-environment, which is coupled to the world by means of its detector-effector capacities (von Uexküll 1926). It is through the capacity to sense that an organism is affected by, and thereafter affects, the world as a result of differences which it perceives and acts on by means of its ability to identify and perform (Bateson 1972). Space is a reflexive phenomenon which is both produced and productive; whereby, for example, the experiential effect of light on a subject influences behaviour and effects action. The former is phenomenological, the latter is organisational. While both aspects are intrinsic to thinking about space, and essential to reconciling disparate treatments of space, this paper focuses on its organisational properties. Christopher Alexander and Bill Hillier et al. illustrate the structural

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properties of space as generative (Alexander 1971; Hillier and Hanson 1984; Hillier 1996); demonstrating how spatial configuration can arise in buildings and cities through the iterative execution of simple rules performed according to local criteria. Proxemics illustrates how, for animals, spatial organisation is affected by distance-sense and bodily expression (Hediger 1955), and how this is extended to cultural parameters in humans (Hall 1966). Proxemics is determined by the distinguishing of boundaries, defining regions of space which may be extrapolated to describe discrete niches that form meta-niches, which form meta-meta-niches. All living things dwell in behavioural niches, and in so doing affect their environment in some way. Furthermore, various organisms have developed the capacity to modify their environment in such a way that they construct artefacts. These structures embody the subject's intelligence. The web defines that of the spider, the dam that of the beaver and a building that of humans. While human beings may be understood to create artefacts 'par excellence' their constructs are ingrained by patterns of inhabitation, i.e., the tendencies and nuances of living beings materialise, becoming transcribed in the artefacts they produce through their activities and capacity to affect matter.

Concerned with the problem of spatial configuration in architecture I propose that 'human-space' may be comprehended by extending the issue downwards in the evolutionary scale to the pattern recognition and control processes of simpler organisms - on the basis that the mechanisms we see at play in single-celled organisms lead to higher degrees of sign processing in humans. Understanding this process to be effected across scales of composition, from the individual to the collective, a cell-centric notion of space is offered. The ability to sense is ambient and distributed, and from this perspective, space is 'lived'. The paper is thus composed of two related parts. It begins with the proposal of a novel and sensory-based concept of space, which is then used to suggest a model that explores the spatiality of an archetypal organism-in-its-environment; capable of configuring an object according to differences in the environment. The configured 'object' may be viewed as articulated spatial intelligence, transforming the distributed cognition of an organism into a method for generating architectural spatial formations.

Towards a Biosemiotic Concept of Space

The concept of space evades concrete definition. Being part of our existence the 'nature' of space has become so extrapolated from the 'nature of dwelling', that it has become separated from the concrete qualities of everyday life. However, seeking a concise definition of space may seem trivial given our capacity to handle and manage spatial problems in daily life. There is a hiatus between our capacity to handle spatial problems and our ability to explain space. Despite the claims of Tim Ingold (2011), space is not nothing.[1] Louis Kahn claimed 'architecture is the thoughtful making of spaces'. A claim which (as an architect) I feel compelled to defend because people,

[1] The claim that "[s]pace is nothing, and because it is nothing it cannot truly be inhabited at all" (Ingold 2011: 145), oversteps the view that space is a void; for whilst Aristotle and Newton held this view the void, for them, was not nothing. Ingold states: "I just cannot get out of my head the idea of space as a void, as non-world, as absence rather than co-presence." (Ingold 2011: 142). Like Descartes (for whom there was only matter and its extension) Ingold seeks to remove space from consideration.

society, space and the environment are intrinsically linked, and the way in which we engage with and manage our world is spatial; making 'space' and its formation fundamental to the practice of architecture.

Our perception of space defines a model of how we see the world. Such preconscious modelling is intrinsic to the way an architect conceives and goes about designing a building. One's notion of space has a significant impact on the manifestation of the built environment, and thus the quality of daily life. After all, we tend to exist in and around built environments. Ingold presents an enticing argument as to the value of space, but our positions regarding its value differ. Like Ingold, I see the world as a world and not an inert void, and that what goes on in the world are processes of life, not time. He speaks of an organism as a meshwork of lines, and the environment as a domain of entanglement (Ingold 2007, 2011). Similarly, Jesper Hoffmeyer explains how an organism is not limited but is coupled to the world by its skin, which is a defining margin through which sign action occurs (Hoffmeyer 1998, 2008). We do not inhabit space in the same manner that an item occupies a container, rather we affect space through interaction with the world. Henri Lefebvre's perception of the world through a spatial lens (Lefebvre 1995, 2004) lends much to this view and elaborates the phenomenon of space and its configuration as something produced, as well as productive. Space is thus perceived to be an active (quasi-material) phenomenon which manifests itself and persists. I propose that space is akin to a nest built by social insects; such as ants, termites and wasps which may include features such as chambers, shafts, galleries and entrance(s) (Tschinkel 2004; Theraulaz et al. 2003). The process of construction is a consequence of environmental changes that feed back on the builders to effect further changes (Theraulaz and Bonabeau 1999). In other words there is reciprocality between what is produced and its production; a process Pierre-Paul Grasse termed 'stigmergy'. The nest opening provides passage to the 'outside', which, while not being a physical aspect of the nest, couples the inside and outside. Notably, the nest is a dynamic form, under continuous construction. Defining a niche for the colony, the nest is formed of auxiliary niches which relate to particular activities and functional requirements; pertaining to the success and survival of the colony. The analogy portrays something, from the ants' perspective, that is, yet isn't.

Arguing 'for' space Doreen Massey (2005), like Lefebvre, posits space a social product because it unfolds through interaction. "Space is neither a 'subject' nor an 'object' but rather a social reality – that is to say, a set of relations and forms" (Lefebvre 1995: 116). Emphasising the social dimension of being in the world Lefebvre stresses that interaction is both mental and physical: "Space is social morphology: it is to lived experience what form itself is to the living organism, and just as intimately bound up with function and structure" (Lefebvre 1995: 94). The manner in which something holds significance to some other, such as to effect a force, is intrinsic to sociality. That there is some effect, between one thing and another, means that these things enter into a relationship, and thus have some form of commonality. The fact that it is the property of significance that brings this relation into being distinguishes this kind of semiotic causation from mere brute force causation (see Hoffmeyer 2007), as the hallmark of relationships established by living beings. We might consider that this effect has some value or that it is self-reinforcing, such that it causes habit – and this relates also to the solitary cell interacting with its environment. 'Social' thus infers some effect between two or more living beings and the mutually constitutive intersecting vectors of significance, and that this effect is reinforcing. Accordingly, the issues of how this effect emerges; how it has (or comes to have) any significance and therefore how its 'substance' is acted on now become other key matters in need of explanation. The semiotic logic of Charles Peirce (1839–1914) is a key to resolving the issue. Together with the theoretical biology of Jakob von Uexküll (1864–1944) and the bio-cybernetic thinking of Gregory Bateson (1904–1980), a 'biosemiotic' backbone is established for exploring the subject. Understanding living systems not only as sign-acting, sign-manipulating and sign-creating systems, but also as products of sign-action, biosemiotics provides a platform from which to examine 'space' as intrinsic to being. If living systems are both products and manipulators of signs, then they are also intrinsically products and manipulators of space as well, because signs almost always involve some spatial dimension.

As a relationship which is produced suprasubjectively across agents, space has objective properties. However it is not an object per se, but a pattern. This pattern is tangible in the sense that it can be perceived – and can be acted upon as a sign. At this most primal level it is a pattern of interaction. As an artefact, formed through an organism's capacity to affect and manipulate its environment, space is further objectified. The definitive manifestation of physical space is thus an artefact, which embodies the spatiality of the organism that created it. Having progressed from congregating around fire, humankind constructs buildings serving purposes beyond basic physiological needs, such as cultural, personal, artistic expression and, more recently, sustainability.

The habitual tendencies of an organism are cast into the artefacts and structures they create. We may extrapolate these forms as embodying patterns, of patterns of patterns, of meta-patterns and so forth, of inhabitation pertaining to the capacities of the organism, i.e., increasing semiotic freedom leads to greater spatial intelligence, which leads to more complex patterns of inhabitation and thus the formation of artefacts pertinent to the organism's being. Space is fundamentally a sign because it is a reciprocal condition of unfolding engagement in the world which, once produced, affects in the manner of a sign; the meaning of which is contingent on the organism. The interpretant feature of the Peircean triad is intrinsic to this reciprocity because, as a second sign, it leads to a progression whereby step changes may occur; thereby extrapolating the generative aspect of space. The actuality of space escalates from its primal state of pure possibility, engendered by a 'difference', to its physical state of generative lawfulness according to the three Peircean categories of phenomena.

Space as an Enabling Constraint

The organisational aspect of space is classified here as having low-dimensional properties, referring to constraints which are rudimentary; effecting direction and distance in a relational sense (see Londey 1955). The phenomenological aspects are perceived as high-dimensional properties because they are experiential. The nature of space is thus exclusive to each living being (von Uexküll 1926). Conversely, these dimensions may be equated to Peirce's categories of Firstness and Secondness. In this sense the high-dimensional properties of space relate to Firstness and the low- to Secondness. "The mode of being of Firstness, is the embryo of being" (Peirce 1903: 269), relating to 'possibility' and the basic manner in which some quality is sensed; such as the effect of light falling through an opening at a certain time of the day. Being rudimentary, the low-dimensional properties are brute facts, whereby actual existences and effects arise out of their relation to other things. The mediation of Firstness/high-dimensional properties of space and Secondness/low-dimensional result in space as lived, or in Peirce's terms, 'Thirdness'; the regularities and habits of the organism-in-its-environment, which, looking back at the nest analogy, manifests form. Habitual tendencies are cast into the artefacts and structures organisms create; what Lefebvre called 'spatial practice': "The spatial practice of a society secretes that society's space; it propounds and presupposes it, in a dialectical interaction; it produces it slowly and surely as it masters and appropriates it" (Lefebvre 1995: 38).

Lefebvre recognised lived-space as mediation between mental and physical aspects of space and identified three ways in which space manifests:

1. Physical space is 'perceived', and constituted through 'spatial practice'
2. Mental space is 'conceived', leading to 'representations of space'
3. Social space is 'lived', which establishes 'representational spaces'

His 'spatial-code' is a trialectic formulation for reading, interpreting and producing the space we live in. Unravelling this code identifies two intertwined triads: "physical-mental-social" and "spatial practice-representations of space-representational space". Frustrated with binary theories, Lefebvre shuns the semiotics of his milieu[2] as "promoting the basic sophistry whereby the philosophico-epistemological notion of space is fetishised and the mental realm comes to envelop the social and physical ones" (Lefebvre 1995: 5). In other words the vicissitudes of the organism-in-its-environment are reduced to an abstract body, 'understood simply as mediation between subject and object'.

Pentti Määttänen (2007) claims coupling the semiotics of Peirce with the spatial-code of Lefebvre establishes a method for analysing the concrete interaction of a living organism with its environment. See left diagram of Fig. 1: adapted by the author from Määttänen (2007). The diagram on the right (by the author) clarifies how, when space is understood to be a sign, this coupling defines a framework for explicating the nature of space and analyses how, in a process of interpretation, we perceive the environment and act in it in order to achieve our goals. As a product of semiosis, space is both a determination (produced) and a representation (productive). At the level of an organism that does not create artefacts, physical-space refers to a pattern of inhabitation which, in Lefebvre's terms, being spatial practice, is produced and, over time, mastered and appropriated. In Peirce's terms spatial practice expresses 'the tendency of things to act as they did on a former occasion than otherwise' forming the organism's habits of action. At the level of an organism that creates artefacts these habits of action are cast into the structures produced by the organism, which thus embody the spatial intelligence of the organism. The absolute existence of space is its physicality, which when considered in retrospect is an expression of spatial intelligence. Lefebvre stresses physical and mental space as assimilated through lived-space. His spatial-code extrapolates the relations between subjects, their space and surroundings as a process of interaction which is practical (Elden 2004). Combining these two perspectives defines a

[2] The Saussure school of semiotics and the priority of linguistics. Lefebvre was not aware of Peirce.

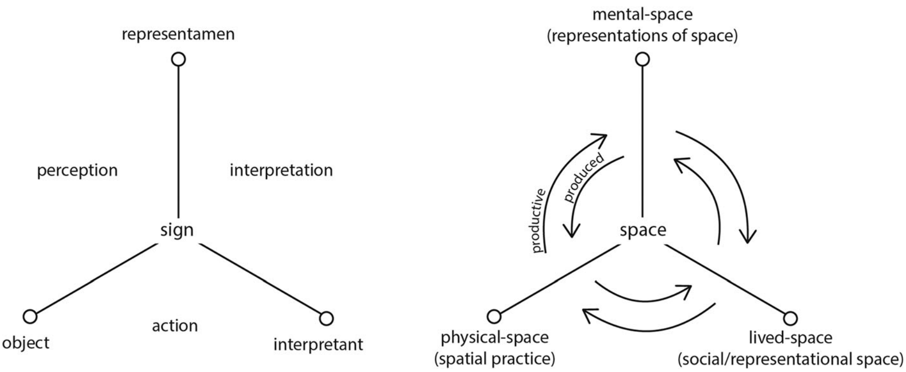

Fig. 1 Space as a sign. As produced (a determination) physical-space determines lived-space, mediated through mental-space (perception of physical-space). As productive (a representation) mental-space and lived-space articulate physical-space through (habits) of action

more fertile concept of space for biosemiotics, providing a framework for thinking about space in terms of the organism-in-its-environment and its biological origins.

The pattern-forming tendencies of natural systems may be embraced as a form of enabling device to generate spatial formations and organisational structures (Bullock and Buckley 2009). For example, pheromone deposited by an ant diffuses and fades, so while it is present only those ants which are nearby and for which the pheromone holds relevance, are affected. The building activities of social insects are driven by environmental cues (such as temperature gradients, air flow, pheromones and partially built structures) which steer activity. Stigmergy describes a kind of indirect, environmentally mediated communication whereby partially built structures direct current building action (Ladley and Bullock 2005; Theraulaz et al. 2003). In other words only those insects in proximity to some cue, and thus nearby in space-time, will be impinged upon and steered to act in some way. *Myxococcus xanthusis,* a species of bacteria, has received much interest of late because of its social behaviour and complex spatial formations (Remis et al. 2014). The components constituting such systems have relevance and their interactions are deictic, effecting meaning and direction. In other words, they are composed of, and producers of, signs which are spatial and, as described earlier, their sociality has spatial consequences and their spatiality has social consequences, recursively. Another aspect is the components embedding in the system they constitute. Taking a swarm as an example, consisting of multiple autonomous components, "spatial embedding enable[s] the population to structure itself in such a way as to maintain co-operative functional organisation through exploiting the 'useful' asymmetries that space introduces into the ecology of interactions" (Bullock and Buckley 2009: 146). Reaction–diffusion, self-organisation, coupling, autopoiesis, habits, sense-making, etc., rely on local interaction and exhibit patterning because the relations between the system's components constrain one another. Defined as 'low-dimensional properties' of space these constraints were, above, equated with Secondness and being triadic are inherently geometrically restrained. Capable of global communication, an ant may message another on the other side of a ravine but then the messenger's instruction needs to be explicit. Fixed on local information, ants don't need to worry about which 'piece' of information, or rather difference, is relevant; only how to decide which to process, and which messages to respond to. Ants don't need a representation of what fellow ants are doing. The colony's conduct is distributed. Living systems are enabled by constraints. Transcending these constraints spawns space and creates problems.[3]

Translated by scientists and engineers, the distributed representation evident in phenomena, such as ant colonies and neural networks has been applied to problem solving. Architects and designers should utilise the organisational characteristics of natural phenomena as a creative resource which they can profitably steer and massage because, once modelled, the system's tendencies may be leveraged and bent to other means and ends (Ireland and Zaroukas 2012; Coates 2010). Why would an architect want to do this? Spatial problems are complex, which traditional methods tend to flatten into something quantifiable so they can be managed and planned; raising the question about whether any richness is lost. There is, too often, a qualitative disconnect between the articulation of spatiality in the built environment and the spatiality of being. Everyday life and the world around us are not determinable, reducible or linear. By engaging with the spatiality of an organism-in-its-environment this issue may be transcended.

A Definition of Space as Purposive

The typical manner in which an architect will start to work up a design is to first identify the constraints of a given site, which she/he will then utilise to determine how the building should occupy the site, thereafter configuring the building. While architects work with constraints, there is an unspoken sentiment that these constraints should be overcome. Constraints are opportunities in disguise. Referring to the way in which self-organising systems employ, what Bullock refers to as, 'spatial embedding' (e.g., a bird within its flock) to generate 'correlation structure' (e.g., the patterns produced by the interactions of birds flocking), Bullock argues these constraints may be manipulated in (architectural) design as curbs to manage and influence the parameters afforded. He claims that reflexive and reciprocal interactions create 'clustering and cyclic or reciprocal interdependencies between a system's parts', encouraging regularities and asymmetries between different elements and aspects of the system in a way that "scaffolds and stabilises interesting and functional organisation" (Bullock and Buckley 2009: 147). In the same way that the low-dimensionality of space affects particular patterns and configurations in a manner which constrains interplay between a system's parts, networks of semiotic interactions control the activities of constituents in a manner which tunes and steers organisation. This is what Hoffmeyer (2007) refers to as 'semiotic scaffolding'. The constraints effected by the low-dimensional properties of space and the semiotic transactions which afford ascendance are interdependent, and it is this reciprocality which scaffolds. In other words, semiotic action and the low-dimensional properties of space coordinate in tandem.

Once deemed to be a primitive condition created through interaction, space emerges and fluctuates as a result of a perceiving entity's interpretation of its surroundings (which is conditional on its state) and the effect of this impression on the environment; a cyclical process of feedback between internal and external factors which coalesce to effect action (cf. von Uexküll 1926). This leads us to consider space as emerging from

[3] Personal correspondence with Professor Seth Bullock (2010).

the coupling of internal and external domains and thus to extend the stigmergic perspective; overstepping the stochastic process of interaction described therein. As a morphological process characterised by 'intentionality', space is organisational, in the sense that it orients and affects future actions; a form of *telos*. It is a reflexive condition which is produced and productive, in continual reinvention. Some characteristics of space comply with those of a complex adaptive system which produces its own organisation, in response to differences in its environment. I propose that the concept of autopoiesis (Maturana and Varela 1980), which explains how a system is created and is self-generating as a consequence of a complex of interactions between its constituents (remembering that these exchanges are deictic), provides a model for considering space a process of (re)construction. The central thesis of autopoiesis echoes what Lefebvre argued of space (see Fig. 1). Constituting a closed domain of relations specified only with respect to the autopoietic organisation that these relations constitute, the concept (of autopoiesis) defines "a space in which it can be realised as a concrete system, a space whose dimensions are the relations of production of the components that realise it" (Maturana and Varela 1980: 88). Transferred to architecture, the concept of autopoiesis enables (or promises) a method of 'social' or 'collective geometry'. It is this aspect which offers architects a fresh (ontological) conception of space, and promotes the idea that computational modelling enables the capacity to organise space and generate spatial formations in a manner which engages with the notion of the organism-in-the-environment.

Taking a pragmatic stance (on the premise that architecture is intrinsically about the creation of settings for everyday life), patterns of activity may be used as templates from which to generate the organisation of a building. Architects have long looked to ideas about the topology of natural forms to inspire architectural designs – but, as we will see, such efforts fall short of a fully biosemiotic consideration of 'space'. Christopher Alexander introduced the idea of 'natural' design (1971) and a formal systems approach (1977). While he has played a significant role in promoting the algorithmic turn in design, his approach explicates a form of mapping between the parameters of a given problem and the conditions to which these are applied. The emergence of form in nature and design involves more than mapping. Both incur some form of supposition in the process of 'becoming', such that step-change(s) take place. Alexander advocates a connectionist approach, which explicates a topological perspective. Likewise, Maturana and Varela (1980) and Kurt Lewin (1936) embraced topology as a means to characterise organisation occurring through networks of association. Autopoiesis (Maturana and Varela 1980) and Varela's concept of autonomy in biological systems (Varela 1979) refer to the topological configuration of networks arising out of component interaction. An autopoietic system, they say, "is defined as a unity by and through its autopoietic organisation. This unity is, thus, a *topological* unity in the space in which the components have existence as entities that may interact and have relations" (Maturana and Varela 1980: 93–94: my emphasis). The quality of spatial relation is not accounted for. A human hand connected to an arm, connected to the shoulder implies discrete parts connected to one another in some way, by which we may define 'a set of parts' connected to other sets of parts which, together, define a meta-set: the body. Drawing on Vitruvius, Renaissance architects employed the body as a means to design buildings, on the basis that the transference defined harmony. Le Corbusier (1946) later picked up the analogy to promote his ideal of modern architecture. The analogy depends on distinguishing boundaries, but where is the boundary between an arm and a hand? Our organs do not plug into our bodies; they are integral and related in such a way that they connect and overlap with other aspects of the body. Spatial relations are more varied than the topological approach allows for. We will look at an alternative to the topological approach in the next section.

This first section has argued that space is a consequence of social cohesion, effected through constraints and processes of enaction which are (fundamentally) semiotic. Space, I claim, can be thought of as a sign because it is a reciprocal condition of unfolding engagement in the world which, once produced, affects in the manner of another sign. As a sign, space is a condition pertinent to an organism's semiotic freedom, which is articulated by the organism as a consequence of its capacity to manipulate the world in the course of its unfolding interaction with its environment (see Fig. 1). A biological definition of space and organisation has thus been presented on the basis that the spatiality of an organism is generated through its capacity to sense, and that this offers a new definition for 'architectural-space'; tying people, society and environment together on the basis that 'biological-space' underpins 'architectural-space'. This view is extended in the next section and a computational model is presented which demonstrates the argument put forward in this section.

A Cell-Inspired Model of Configuration

Activity is perceived to be the basic building block of spatial configuration in architecture. An activity in isolation is meaningless. Having an input and output, an activity exists in a chain of action; affected by that which has preceded and affecting that which is to transpire. Topology, describing space as a set of points, accounts for this chain because it depicts connectivity and the convening of points to describe form. However, as events, activities can have equivalence in terms of location, occurrence and so forth. Spatially they may have varying degrees of correspondence. Mereology, a theory of parthood relations, takes regions (as opposed to points) as the ontological primitive. Coupling topology and mereology (known as mereotopology) defines a more concrete analysis of spatial conditions (Cohn and Hazarika 2001).

Human activity has developed in-line with social and technological change and our changing patterns of activity have transpired to affect the evolution of built space; revealing a pattern of progress since humankind first progressed from congregating around the campfire. Strangely enough, as discussed in Part 1 and as Bryan Lawson remarks, architects "tend to consider space as an abstract concept and not a behavioural phenomenon, and yet paradoxically assume that behaviour will follow their predictions" (Lawson 2001: 200). By taking a distributed approach this gap may come to be bridged. The spatial salience of an organism is an effect of its distributed cognition (Cárdenas-García 2013), and this is constructive. On the basis that design is a constructive activity (Glanville 2006), the distributed cognition of an archetypal organism may be transferred to designing on the basis that 'to design, is to configure'; meaning to arrange elements or parts in a particular way so as to satisfy some need - and that this is akin to the development and survival of an organism-in-its-environment. Leveraging the behaviour of natural phenomena in such a way that their activities and goal-seeking behaviour (such as the morphogenesis of slime molds and social insects nest building) may be bent towards design (cf. Liu and Tsui 2006).

In the model that I am now going to propose, the collective (social) behaviour of distributed (swarm) systems is utilised, to capitalise on their constructive (i.e., nest building) and configurational activities (i.e., agglomeration of slime molds and food foraging in ants). The distributed pattern forming and constructive tendencies of these phenomena are adapted to the problem of configuring architectural space, upturning the traditional architectural approach, to demonstrate the position on the concept of space argued in Part 1.2. Figure 2 depicts the exemplary of the model to be presented, illustrating how configuration arises from a disorganised to an organised arrangement. It serves two purposes. On one side it is an abstract illustration of an autonomous system composed of various constituents. On the other it illustrates a (computing) methodology. It describes a qualitative-semiotic conception of spatial configuration incorporating three levels of construction. At the base-level, discrete components with semiotic competence come into relation with one another; forming associations between them. These semiotic-components detect what is out there and, distinguishing a difference, respond relative to a corresponding (stored) value, thereby acting on the difference detected. As these associations form, they constrain the behaviour of individual components to define couplings between associates which coalesce; forming compositions which reflect their form of association mereotopologically, i.e., they are connected, touch or have some form of overlap. These associations steer interaction between couplings to form assemblages which, at the mid-level, define patterns of association. In other words level one is the defining of relations between discrete components, which come together to form parts at level two. These couplings are then steered by new or unrealised associations which subsequently form new couplings at the third level to form a body of parts. This ascension could of course consist of manifold levels in which component parts form parts of parts, which in their own right form bodies, which constitute meta-bodies, and so on. Figure 2 may therefore be redrawn as a series of moments articulating the development of form, instead of, as it does, the three step-changes described:

1. Disordered discrete components at the base level, in which two are shown to be coming into a relation (emphasised by the inset illustrating the emergence of overt behaviour) which drives them to couple;
2. the spatial articulation of these couplings in which the components coalesce to form parts, which
3. come together to form a body of parts, articulated by the dashed line to emphasise the formation of a whole.

To illustrate the process portrayed in Fig. 2, a computer model is now implemented and used to demonstrate a distributed approach to configuration.

The computer model is agent-based, meaning it is composed of various entities which have autonomy and act according to rules (see Franklin and Graesser 1996). The basic component of the computer model is an actant[4] which represents a region of space

[4] A term borrowed from Bruno Latour (1996) to refer to an autonomous entity-in-its-environment.

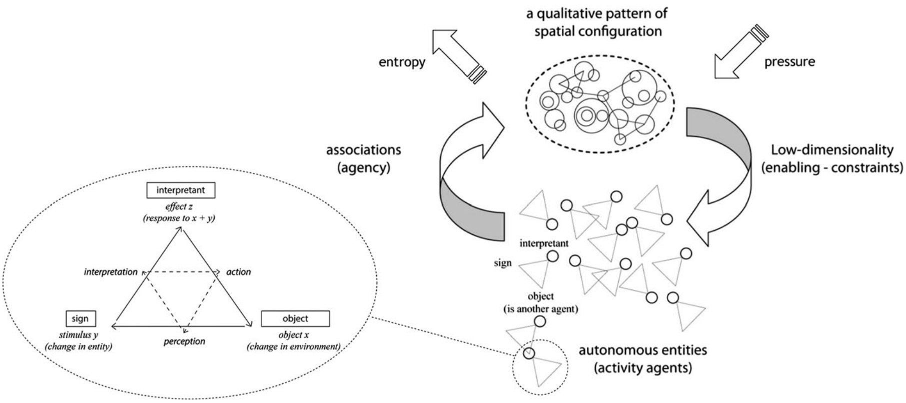

Fig. 2 The proto-model system of configuration

specific to a discrete activity. An actant is an (abstract) semiotic entity, composed of discrete semiotic components. The model is composed of various actants (which are swarm-like entities) that coalesce with other actants they share relations with to generate an aggregation; articulating a pattern of activity. The actants thus act like a slime mold, whereby the individual spores agglomerate when starving, to form a single body. The model is thus conceived to be (or to generate) a 'body of swarms'; predicated on an argument presented by Hoffmeyer in his paper "the swarming body".[5] The notion of an organism as a swarming body is an analogy, described as a hierarchy of overlapping swarms (of swarms) creating an assemblage of cohabitation. "At all levels these swarms are engaged in distributed problem solving based on an infinitely complicated web of semetic interaction patterns" (Hoffmeyer 1994: 938). Another contribution informing this model is a hypothesis of organism-environment relations by Barry Smith and Achille Varzi, who present a general theory of niche dynamics to explain how population interactions are projected into the spatial dimension (Smith and Varzi 2002). A general hypothesis is thus proposed, for creating causally relevant spatial regions that generate spatial formation in a cell-like manner. The principles of this model revolve around the concepts of 'niche' and 'boundary'. The former is based upon formal predicate relations for 'location', 'region' and 'niche' drawn from Smith and Varzi (1999). However, before looking at these concepts we will look first at what an actant is.

An Actant

Figure 3 illustrates the composition of an actant; the basic component of the model. The boundary is a mutable entity whose configuration affects the region, representing a discrete space-of-activity. The boundary consists of nodes (boundary-receptors) which are affected by differences, that effect a centrifugal or centripetal force, affecting the actant's location relative to the difference detected. The boundary-receptors thus move collectively while emitting and responding to differences they detect; which I will from here on in refer to as 'semione', to denote any kind of sign-vehicle an actant is capable

[5] The idea for this model preceded my review of Hoffmeyer's paper, but the notion therein presented consummated the idea.

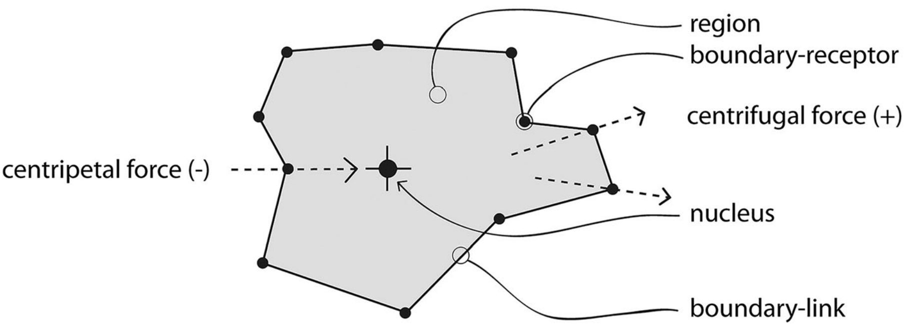

Fig. 3 An actant is an autonomous entity with sensorial capacity

of emitting or receiving. Being linked, the boundary-receptors define a boundary and describe the actant's form. An actant deposits a unique semione, thereby identifying itself. Each actant has identity, which its components share; represented by colour and an index to which the other actants refer. A difference may therefore be 'observed' by a boundary-receptor as something which is not an aspect of its actant's identity, which it thus responds to by positioning itself according to its association with the other actant detected. The actants configure themselves according to those actants they have an association (or dissociation) with by responding to their semione. The nucleus represents the organism (performing 'x' activity), and the boundary delimits the region pertaining to the activity the actant represents. Configuration arises in the model as a result of boundary conformation, determined by the way the boundary-receptors respond to differences detected; acting in accordance with the associations their actant has with other actants.

An actant moves via the collective actions of its boundary-receptors, which move relative to their distance from the nucleus and nearest boundary-receptor neighbour. The former is a simple attract-repel mechanism[6]; the latter a repel mechanism from the closest boundary-receptor of the same actant. This results in a wandering-like behaviour in which the collective moves in a unified manner, reminiscent of the movement of amoebae. An actant wanders in this way for a period until, if no other actants are sensed, one of its boundary-receptors extends outwards to become a 'hunter'. Having done so, the hunting boundary-receptor will move away from the nucleus, extending the actant's search space to seek associate actants beyond its immediate vicinity. If another boundary-receptor is perceived, the hunter will position itself according to the relation between the two actants: see right-hand image of Fig. 4. Otherwise the hunter switches back to boundary-receptor state and settles back. This hunting action is analogous to the cellular extensions of amoeboid type cells used in moving and feeding. The propulsion of the extension can affect the course of the actant's wandering. If no associate is sensed after another period of wandering the hunting behaviour is repeated. The autonomy and sensorial capacity of an actant means that its form is changeable. It is a mutable figure affected by the conditions in which it is situated, which is diachronic: being affected by motion, the actant's composition, and its causal relations. As the interface between variant domains, through which communication is

[6] If a boundary-receptor is too close to the nucleus it will step away from it, and if too distant it will step towards it.

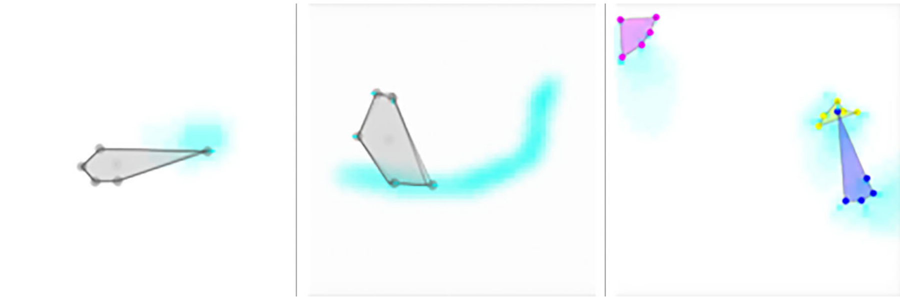

Fig. 4 Actants responding to semione. (Left) to a semione source, (centre) following a semione trail, and (right) engaging with an associate actant

effected and difference is maintained, the boundary is conceived a form of agent affected by the multiplicity of interactions between actants with their own timing, spacing, goals, means and ends (Latour 1996; Hoffmeyer 1998). Two matters fundamental to the model's conception, and integral to the definition of space presented in Part 1.2, are boundaries and how the presence of a boundary explicates a niche. We look first to the matter of boundaries.

Boundary Conditions

An actant's boundary represents the incorporeal limits of a discrete activity, and may be construed in two distinct ways. Firstly, the actant's boundary is depicted with lines connecting boundary-receptors, so from the observer's perspective, a physical condition is inferred. Secondly, from the actant's perspective these physical limits don't exist; only semione and the distinction thereof are present. Smith and Varzi (2000) differentiate two types of boundary. Bona-fide boundaries are literal and relate to concrete physical objects, while fiat boundaries (such as between one country and another, or an arm and a hand) are a construct of perception. An actant represents a discrete activity and thus what their boundary articulates is fiat, because being an indirect by-product of an organism's behaviour patterns the boundary of an activity is a construct of perception (Smith and Varzi 2001). The configuration of the actants results from their boundary conformation to context, represented tangibly and effected via the sensibility of their boundary-receptors. The presence of semione is particular to each actant, according to meaning and proximity. Semione distinguished by a boundary-receptor is an object of focus; causing the actant to be oriented. The tangible boundary of the actant is thus a fabrication, expressing the fiat bounds of activity to articulate the behaviour pattern of an archetypal organism-in-its-environment.

William Mitchell (1998) describes architecture as 'an art of distinctions'; between solid and void, internal and external, and so on; determining boundaries between categories around which differences are recognised, and thereby manipulated. The act of distinguishing is a process of construction which brings the world into focus; transformed from an amorphous muddle into something which can be read, because aspects are composed by the individual into distinct parts which are organised in some particular way. "One important motor for the drawing of ephemeral fiat boundaries is perception, which as we know from our experience of Seurat paintings has the function of articulating reality in terms of sharp boundaries, even when such boundaries are not genuinely present in the autonomous physical world" (Smith and Varzi 2000: 405). The focus of concern, in architecture, is typically (bona-fide) built form, emphasised earlier by Lawson. Hillier et al. express the morphology of social relations encapsulated in built forms to reveal the structure of the fiat operating from the bona-fide. It is the reciprocity between the bona-fide and fiat bounds which I seek to mediate, and with this model generate fiat bounds to (with further work) establish bona-fide bounds. The methodology (see Fig. 2) thus evokes configuration a process of agency between tangible and perceived. The model presented takes a distributed, as opposed to an authoritative, approach, which transpires as a result of the collective capacities of the actant (i.e., the components constituting it) and the actant population. Additionally, in the model presented, the authoritative self that Mitchell describes distinguishing between differences is parsed to the collective, constituting the (archetypal) organism-in-its-environment.

Hoffmeyer's (2008) appraisal of the semiotic self is central to the conception of this model and the notion of space presented in Part 1. Hoffmeyer describes a semiotic loop between internal and external domains, and looks at the skin as an example of a semiotic interface through which orientation is effected, and the variant conditions on either side of the division are managed. Reiterating Smith's (1997) account of 'oriented' boundaries, Hoffmeyer refers to the self (inner domain) as existing "only in so far as that which is inside contains an intentionality towards, or reference to, that which is outside" (Hoffmeyer 2008: 174). Likewise, Bruce Weber describes the cell as a model of the ontology of 'self'. "All cells have a membrane barrier of phospholipids that encapsulates them, providing an osmotic barrier for molecules and ions, as well as defining self from not-self and environment" (Weber 2009: 347). While no sign action occurs across an actant's boundary they have the capacity to distinguish self from not-self, and are oriented via their ability to identify semione. The model's composition is an articulation of transaction between internal/external domains, and development of the model resides in incorporating some such form of transaction. Imagining an organism's pattern of inhabitation composed of discrete activity-niches we now look at how these discrete niches may combine to form aggregations as a result of their relations and how these translate spatially.

The Concept of 'niche': Conceiving the Space-of-Activity as Discrete Components

The term 'niche' may be understood in various ways relating to the notion of fitting; concerning an area which is, or may be, occupied. Hutchinson (1957) expressed the ecological domain of an organism, or population of, as an *n*-dimensional hyper-volume. I focus here on the token niche of the individual organism, conceived a meta-niche, composed of various discrete niches, which an organism occupies in the course of its existence; or some discrete period thereof. Spatially, these discrete niches (representing discrete activities) are composed of an organism, boundary and region. The boundary is fiat demarcating the region encompassing the organism (see Fig. 3). Smith and Varzi (1999) describe the occupant-region-boundary composition functionally. Firstly, all niches are connected (i.e., they have a topological relation), because even though a niche may be separate (having no specific or physical relation) to a neighbouring niche, its existence may affect another; reiterating the aspect that an activity does not exist in isolation, but is part of a causal chain. Secondly, a niche is analogous to the skin or hide of an organism, protecting the occupant by regulating different types of causal flows (Smith and Varzi 2001). Orientation is thus intrinsic to the composition, such that there is intentionality towards, or reference to, that which is outside. (See Fig. 4). In other words, like Hoffmeyer, they define the boundary a controlling mechanism which effects coupling between inside and outside domains. Ross Ashby (1958) similarly describes, albeit mechanically, the boundary between internal and external domains as a causal barrier, or regulating device, which demarcates and protects the internal condition. In effect, the position on space presented in the first part of the paper is a niche-like notion; explicated through the categories of Peirce and Lefebvre's spatial-code. Perceiving the ontology of configuration semiotically, we interpret how one thing connects to another, and the resulting configuration mereotopologically, i.e., how one component is spatially related to another, and that this is qualitative. The occupant is the centric feature, oriented to the boundary, which may relate to things external in a centrifugal, centripetal or nonchalant manner. It follows from Part 1 that the organism-in-its-environment is a fusion, so the meta-niche of an organism must unfold reciprocally (see Fig. 2); envisaged in the model through the actants agglomerating.

Actant-Actant Interaction

The associational possibilities between one activity and another are numerous. Activities have environmental qualities which may occur as inputs or outputs. For example, the need for certain lighting or noise conditions are inputs, whereas the effect of an activity is the level of noise or smell it may produce, which are outputs. Activities have social properties; they may be private or public, and may be cultural. The effect of these properties on the association between one activity and another may be positive, negative or of indifference, resulting in forces for conjunction (positive), disjunction (negative) or negation (indifference). These forces may have measures, and may be defined as a scale, which can be transferred to the actants as a means by which to (self) organise according to their association to other actants.

The form of association and behaviour of an actant is determined by its capacity to sense, and distinguish differences present in the environment. Accordingly, in my model an actant is equipped with the capacity to 'smell', which is enabled through the capacity to distinguish contrasting forms and levels of semione. Being a signal, the semione has meaning for an actant; to which it responds. If the relation is positive it will follow the semione 'uphill', towards the source of production. (See Fig. 4). If the relation is negative it will follow the semione 'downhill', moving away from the source. This attract-repel behaviour is reminiscent of predator–prey relations. Having detected an associate actant, the actant will position itself according to the relation between it and the other, which it does by way of its boundary-receptors positioning themselves accordingly.

Figure 5 shows possible interactions between one actant and another (stemming from Smith and Varzi 2002). These interactions relate to various cases of two-tenant/

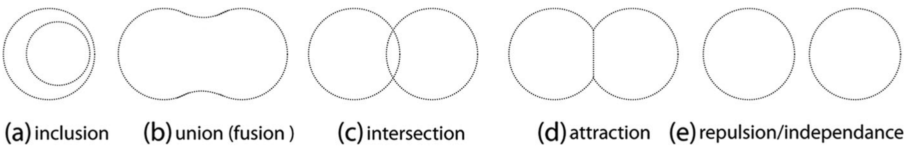

Fig. 5 Possible niche interactions

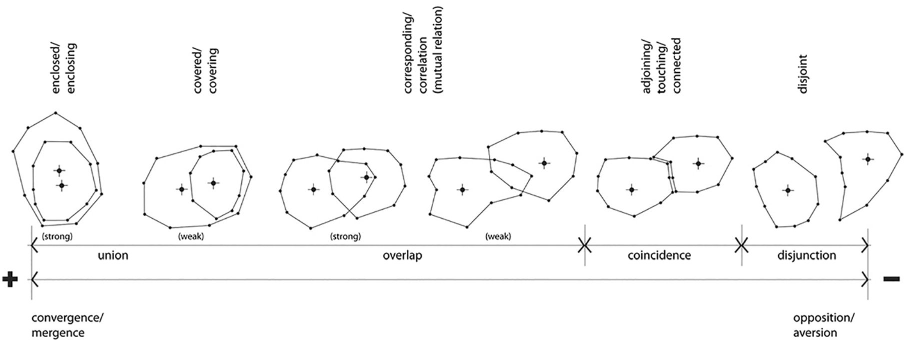

Fig. 6 Relation potentials

two-niche interaction, such as one tenant encroaching on the domain of another; and in the case of the model, one actant encroaching on another. We might, in the first instance, imagine a friendly encounter, whereby the individuals are allied or congenial; a sociable condition in which the niches combine or fuse, articulated by ‘a’ and ‘b’. Of course ‘a’ may also be viewed negatively, as dominance. A positive encounter may transpire whereby the two join but remain separate, as in ‘d’; which may alternatively be a case of hostility. In the case of ‘c’ the two may be disassociated while having a neutral disposition to one another, in which case the two niches remain separate but may overlap. Else there may be hostility, or one may be contrary to the other, causing deformation (in the case of ‘d’) or repulsion (in the case of ‘e’). We thus see (from left to right) instances of coupling, nonchalance, encounter (which may be a collision or impingement) and contrast (which may be conflict or incompatibility). Withstanding ‘c’ and ‘e’, the exchanges lead to deformation. These forms of interaction are applied to the actants to serve as the basis for their agency; defining the manner in which they may interact, and how this interaction may be projected spatially. Figure 6 illustrates how these interactions may be projected spatially, defining a series of relation-potentials, which are subsumptive. The relation-potentials distinguish the spatial-property of a relation as a scale, not of dimension, but as a gradient or degree of consolidation.

Model Results

The actants’ behaviour (see Fig. 4) and the results (see Fig. 7) illustrate configurations resulting from autonomous interacting bodies, which are themselves composed of autonomous components that can distinguish self from not-self. Each time the model is run the configuration is a result of the actants associations, but the formation is a different expression. Different patterns result from the same rules, because the actants’ agglomeration is effected by the endeavours of the population. The resulting configuration is a description, not a definitive solution. The overlapping is achieved by the boundary-receptors determining whether they reside within the confines of another actant or not. If a boundary-receptor is located within another actant’s region the two actants overlap. The degree of overlap may then be determined by the number of boundary-receptors an actant has in another’s region.[7] Actants adjoin if their boundary-

[7] Not a definitive account of the extent of overlap. Only a metric calculation would determine the amount.

receptors detect an associate boundary-receptor in their field-of-view: indicated by the larger shaded circle encompassing boundary-receptors in Fig. 7.

Future development will concentrate on enabling the associations to arise, as opposed to be being fed in, through the intermixing characteristics of the activities inputted and the 'forces' this creates. A key motive for enabling the associations to arise is that the properties of activity are not so straightforward; and fixing them relies on the understanding of the operator. Activities take on different characters in relation to context and the disposition of the 'actor'. The associations between activities are not fixed but have tendencies, which fluctuate depending on physiological and social needs. While the model as it stands does not allow for such 'fluctuating' relations, the configurations arising are the result of the actant's individual timing, spacing and goals. While the resulting configuration satisfies the individual actant's associates, the arising configuration is different each time, because history is a significant aspect of the model. Figure 7 illustrates typical differing results articulating the same actant relations. The actants' 'behaviour' is tensive, because an actant that has settled (once it has satisfied its associations) may become unsettled by another actant's actions. This can cause the overall configuration to unravel, because if a settled actant's associate is unsettled it is then caused to move; spoiling the settled actant's state of harmony, causing them both to re-seek their state of cohesion. This is good, because the final configuration rests on the harmony of all actants realising their individual associations. Configuration in the model is aggregative, occurring through the individual actant's conformation. The concluding configuration is thus determined by the behaviour of the population.

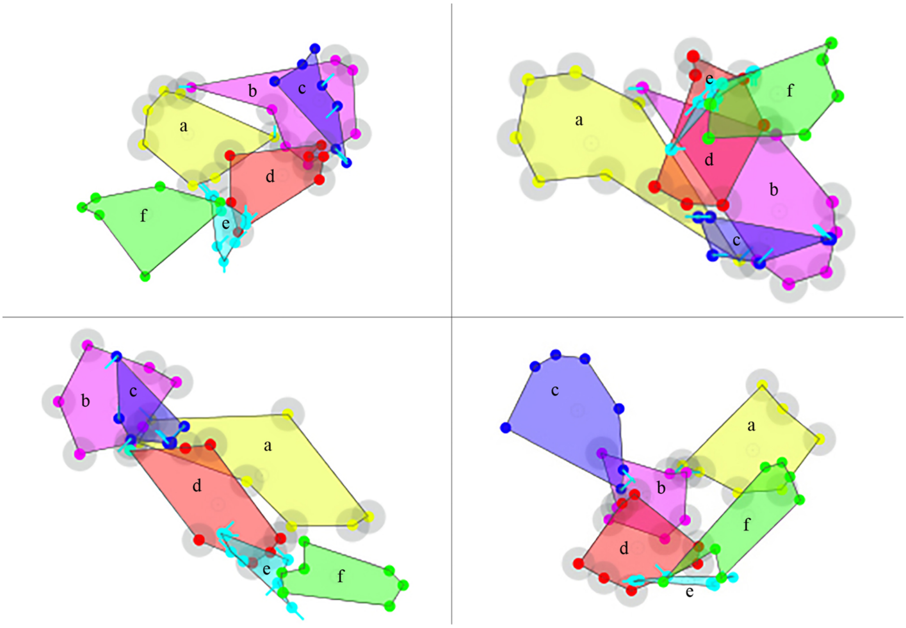

Fig. 7 Several actants settled in different configurations satisfying the same associations: 'a' adjoins 'b', 'c' intersects 'b', 'd' adjoins 'c', 'e' intersects 'd' and 'f' intersects 'e'

The boundary-receptors exemplify the basis of Fig. 2; since it is through these that the relations between actants are formed. However, while there is sign-action no semiosis arises in the model: see Fig. 1 and inset of Fig. 2. Configuration emerges through the actants response to semione but the actants themselves and their associations are defined. As it is they come together to articulate their discrete associations (level two), which form a cohesive body (level 3). The distinction behind level one raises a key issue with the model. The model exemplifies a self-organising process and the arising configuration is (computationally) emergent, but the actants have pre-defined components and the associations between are planned. The actants may be devised autopoietically, such that their boundary conformation is maintained and not constructed a priori. However, while such a change would make the model more interesting and 'lifelike', it is unlikely this revision would significantly alter the forms of configuration achieved presently. Alternatively, manufacturing a means for the relations between the actants to emerge, as opposed to being calculated, would be a significant benefit because, currently, the model simply produces configurations articulating programmed inputs. This development would require semiosis to occur in the model (emphasised by the inset of Fig. 2) to drive activity, and thereby the materialisation of spatial formation between components.

Conclusion

It is difficult to discuss space without falling into the trap of terminology, or rebounding between those prevalent treatises on space which have become so ingrained. Instead, what has been described may be explained using different terminology and thereby express a different perspective on space. Ingold (2011), for example, would argue that space is a frustrating idiom because we inhabit an environment, not space; have our feet on the ground, not space; an artist paints the landscape, not space; a farmer ploughs a field, not space and so on. While this is true, none of these metaphors relate to my perspective of space.

In short, what is proposed is a general hypothesis for creating causally relevant spatial regions that generate spatial formation in a 'cell-like' manner (cf. the catenary model of La Sagrada Família by Antonio Gaudi, the tensile structures of Frei Otto, and the more contemporaneous Embryological House of Greg Lynn). The model is a work in progress. It is a prototype which demonstrates the position argued for in Part 1 and the approach outlined in Part 2. The actants are not cell-like, they are cell-inspired. The model presented draws on the idea that space is an underlying property of natural and animate systems, which is productive, and articulates an approach to configuration that seeks to capitalise on the way space canalises systems into regimes that spontaneously exhibit useful order (see Bullock and Buckley 2009).

The spatiality of an organism is affected through its capacity to sense, which underpins spatial intelligence and capacity to engage with the world. There is a binding connection and reciprocal influence between the environment of an organism and its behaviour, which affects an organism's being and the activities it performs; and which is reflected in the model as the actants realise their associations and agglomerate (according to the social proclivity of the activity represented) and thereby restrict one another. There is a structural coupling between intention and the environment, in much the same way that space, as lived, and mathematised space are two-sides of the same coin. Architectural space may thus be derived from the properties of unity between an organism and its environment, or another organism which may be construed as part of that environment. The premise being that some characteristics of space comply with those of a complex adaptive system which produces its own organisation, in response to differences in its environment. What has been proposed is a conceptual materialisation of spatial configuration, in a way reflecting the behaviour of spatial formation found in natural systems: such as slime mold aggregation.

Space is a property of life, as are signs. Both have materiality and form, but neither can be rationalised in the same way as an object because, while they have physicality, they are not physical. Just as perception and action are interdependent (von Uexküll 1926), so are signs and space. Claiming space is a sign transcends categorising the matter, and thereby having to reconcile how signs and space interrelate. Recognising space as a sign is an ontological view of the spatiality of being, and enables designerly thought the freedom to think about the configuration of concrete space, in relation to the practice of everyday life. The swarming-body model constitutes a closed system (Maturana and Varela 1980) and articulates the spatial salience of biotic being. The concepts of difference (Bateson 1972), boundaries (Smith 1997; Smith and Varzi 2000), and agency (Hoffmeyer 2008) are emphasised as intrinsic to the problem of configuring space. A biosemiotic notion of space is presented, uniting the three major themes of this thesis (architecture, computing and biology) to establish an approach to the problem of spatial configuration which does not flatten the complexity of spatial problems but rather embraces it. The swarming-body model manages the reflexivity of spatial organisation to present an approach to configuration that goes a little way in closing the conceptual gap between architectural endeavour and everyday life.

My analogy of the ant colony's nest serves to illustrate how space is something which has form, is thus structural, and is so because it is an integral aspect of being in the world. We are coupled to an environment through our senses, and we affect the world through our capacities to affect. Like an ant's nest, space is something which is in continual reinvention - as is my perspective!

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